Article Daniel Pauly

The *Sea Around Us* Project: Documenting and Communicating Global Fisheries Impacts on Marine Ecosystems

The *Sea Around Us* Project, initiated by the Pew Charitable Trusts in Philadelphia, PA, and located at the Fisheries Centre, University of British Columbia, Vancouver, Canada, started in mid 1999. Its goal was (and still is) to investigate the impact of fisheries on marine ecosystems and to propose policies to mitigate these impacts. Although conceived as a global activity, the project first emphasized the data-rich North Atlantic as a test bed for developing its approaches, which rely on mapping of catch data and indicators of ecosystem health derived from the analysis of long catch time series data. Initial achievements included mapping the decline, throughout the North Atlantic basin, of high-trophic level fishes from 1900 to the present and the presentation of compelling evidence of change in the functioning of the North Atlantic ecosystems, summarized in a 2003 book. The Central and South Atlantic were the next basins to be tackled, with emphasis on the distant-water fleet off West Africa, culminating in a major conference in Dakar, Senegal, in 2002. The project then emphasized the North Pacific, Antarctica, and marine mammals and the multiplicity of tropical Indo-Pacific fisheries before it turned completely global, with all our major analyses and reports (e.g., on the interactions between marine mammals and fisheries, on fuel consumption by fleets, on the catches of small-scale fisheries, on subsidies to fisheries) being based on global studies. Broadly, the work of the project is aimed at a reappraisal of fisheries, from the benign activity that many interested people still perceive them to be, to a realization that they have become the driver for massive loss of biodiversity in the ocean. Moreover, the emphasis on global estimates (rather than local estimates of dubious generality) has allowed the project to contribute to various global initiatives (e.g., developing the Marine Trophic Index for the Convention on Biological Diversity, quantifying marine ecosystem services for the Millennium Ecosystem Assessment), that is, activities that we expect to increase and for which we invite collaboration from academia and environmental nongovernmental organizations.

INTRODUCTION

The outlines of what is now seen as the global crisis of fisheries became visible in the mid 1990s, with the realization that the collapse of the intensely studied and managed Northern cod (*Gadus morhua*), off Newfoundland and Labrador, Canada (1), could be seen as representative of fisheries as a whole (2) (Fig. 1). Simultaneously, there was a realization that fisheries have a strong, often devastating, impact on the ecosystems in which they are embedded (3). However, the 1990s also demonstrated that governments' regulatory agencies were, in most countries, not ready to tackle these problems and indeed often lacked essential data, such as realistic catches, on key fisheries (see below).

The *Sea Around Us* Project was initiated in 1999 by the Pew Charitable Trusts, Philadelphia, PA, in response and is based at the Fisheries Centre, University of British Columbia, Vancouver, Canada. The project was named after the book of the same name by Rachel Carson (4), one of the author's heroes (another is Charles Darwin [5]), and its goal was to investigate the impact of fisheries on marine ecosystems and to propose policies to mitigate these impacts. More precisely, the project dedicated itself to answering the following questions:

i) What are the total fisheries catches from marine ecosystems, including reported and unreported landings and discards at sea?
ii) What are the biological impacts of these withdrawals of biomass for the remaining life in the ecosystems?
iii) What would be the likely biological and economic impacts of continuing current fishing trends?
iv) What were the former states of these ecosystems before the expansion of large-scale commercial fisheries?
v) How do the present ecosystems rate on a scale from healthy to unhealthy?
vi) What specific policy changes and management measures should be implemented to avoid continued worsening of the present situation and improve the health of ecosystems?

The following text outlines how these various questions were approached and answered, the institutional linkages that we created in the process, and the media used for the dissemination of results. The global scope of the project is emphasized because this is, outside of the United Nations systems, one of the few initiatives working on a global basis on marine ecosystems.

Although conceived from the onset as a global activity, the project first emphasized the North Atlantic. This area is data rich and provided a good test bed for our various approaches, which rely on mapping of catch data and indicators of ecosystem health derived from the analysis of long catch time series data (6). Initial achievements included mapping the decline, throughout the North Atlantic basin, of high-trophic level fishes from 1900 to the present and the presentation of compelling evidence of change in the functioning of the North Atlantic ecosystems, summarized in a 2003 book (7).

The Central and South Atlantic were the next basins to be tackled, with emphasis on the distant-water fleet off West Africa, and culminating in a major conference in Dakar, Senegal, in 2002 (8).

The project then emphasized the North Pacific and marine mammals (9), Antarctica (10), and the multitude of tropical Indo-Pacific fisheries (11) before it turned completely global, with all our major analyses and reports (e.g., on the interactions between marine mammals and fisheries, on fuel consumption by fleets, on the catches of small-scale fisheries, on subsidies to fisheries; see below) being based on global studies.

THE MAPPING OF CATCH AND DERIVED QUANTITIES

Because it involved the impact of fisheries on ecosystems, which, however they may be otherwise perceived, imply a "place," the first task of the project, addressing the first three of the above questions, was georeferencing the catches of world

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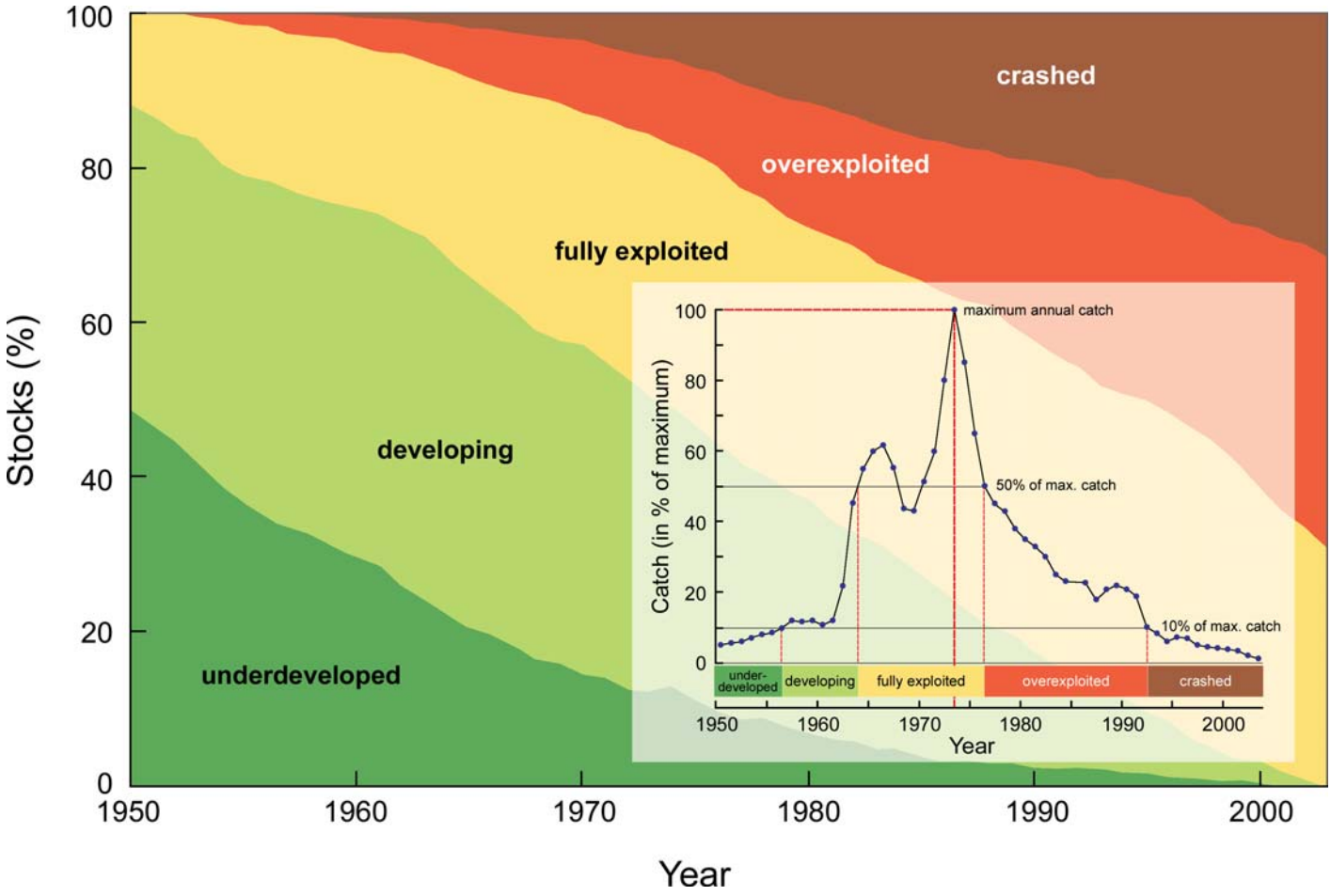

Figure 1. Time series of the composition of global marine fisheries catch according to the status of the stocks making up that catch, 1950–2003. This status (underdeveloped: 0–10%; developing: 10–50%; fully exploited: above 50% of maximum; overexploited: 50–10%; and crashed: 10–0%) is defined with respect to the highest catch of each time series (see insert for example), representing one stock, usually a species, within 1 of 18 FAO statistical areas covering the world ocean. More elaborate, but similar graphs were developed by FAO to generalize regional and global trends. Dr. Rainer Froese of Kiel University simplified these graphs to their present form, which can be used for predictive purposes (e.g., by projecting into the future the border line between overexploited and crashed).

fisheries, that is, putting them back in the ecosystems from which they were taken.

However, except for tuna, fisheries data are usually not presented in spatially disaggregated form. Moreover, data on who caught "what and where" usually exist only for fisheries with on-board observers, tend to be confidential, and cover only a small part of the world's fisheries.

Hence, to place fisheries catches on maps, we had to use other things that we knew, notably that the catch of each species must originate from within the distribution range of that species and be reported by a country that has access (legally or not) to that distribution range.

World fisheries catches, documented since 1950 by the Food and Agriculture Organization of the United Nations (FAO), regionally by such bodies as the International Council for the Exploration of the Seas, and by individual countries, include about 1200 taxa (more than 900 fish and invertebrate species, the rest being reported at the level of genera, family, or higher), for which we constructed distribution range maps (12) (Fig. 2, item 5), recently much improved (13), and all are available at the project website (see below).

These distribution ranges, combined with a database of more than 5000 agreements regulating foreign access to the Exclusive Economic Zones (EEZ) of maritime countries, allowed a rule-based allocation of the reported catches of the world, from 1950 to the present, to 180 000 half-degree ocean cells.

Since it was devised and used to great effect (e.g., to demonstrate that catch over-reporting by China had masked the true trend of world fisheries catches [14], which started to decline in the late 1980s), this allocation system has been steadily improved and now represents the backbone of the project (Fig. 2, items 1 and 2) and of its output, be it published (15–18) or available at the project's website (http://www.seaaroundus.org).

This applies especially to the market value of fisheries catches, estimated as the product of the georeferenced catches mentioned above, times prices, the latter from a database we created of ex-vessel prices of marine fish and invertebrates in different countries (19).

It does need to be emphasized that information on the value of fisheries is crucial in fisheries management, such as in negotiations of fishing access agreements between developed and developing countries. The absence of widely available databases on prices may be, indeed, one of the reasons for the asymmetry of the access arrangements so far negotiated (20).

Also, the data are presented so as to allow straightforward bioeconomic analyses of the fishery sector (Fig. 2, item 14) or of individual fleets (21), especially in developing countries, for which such price and value information are often lacking.

MAPPING FISHERIES INTERACTION WITH SENSITIVE HABITATS, MARINE MAMMALS, AND SEABIRDS

The catch maps that the *Sea Around Us* Project developed can also be used to visualize the interaction of fisheries with

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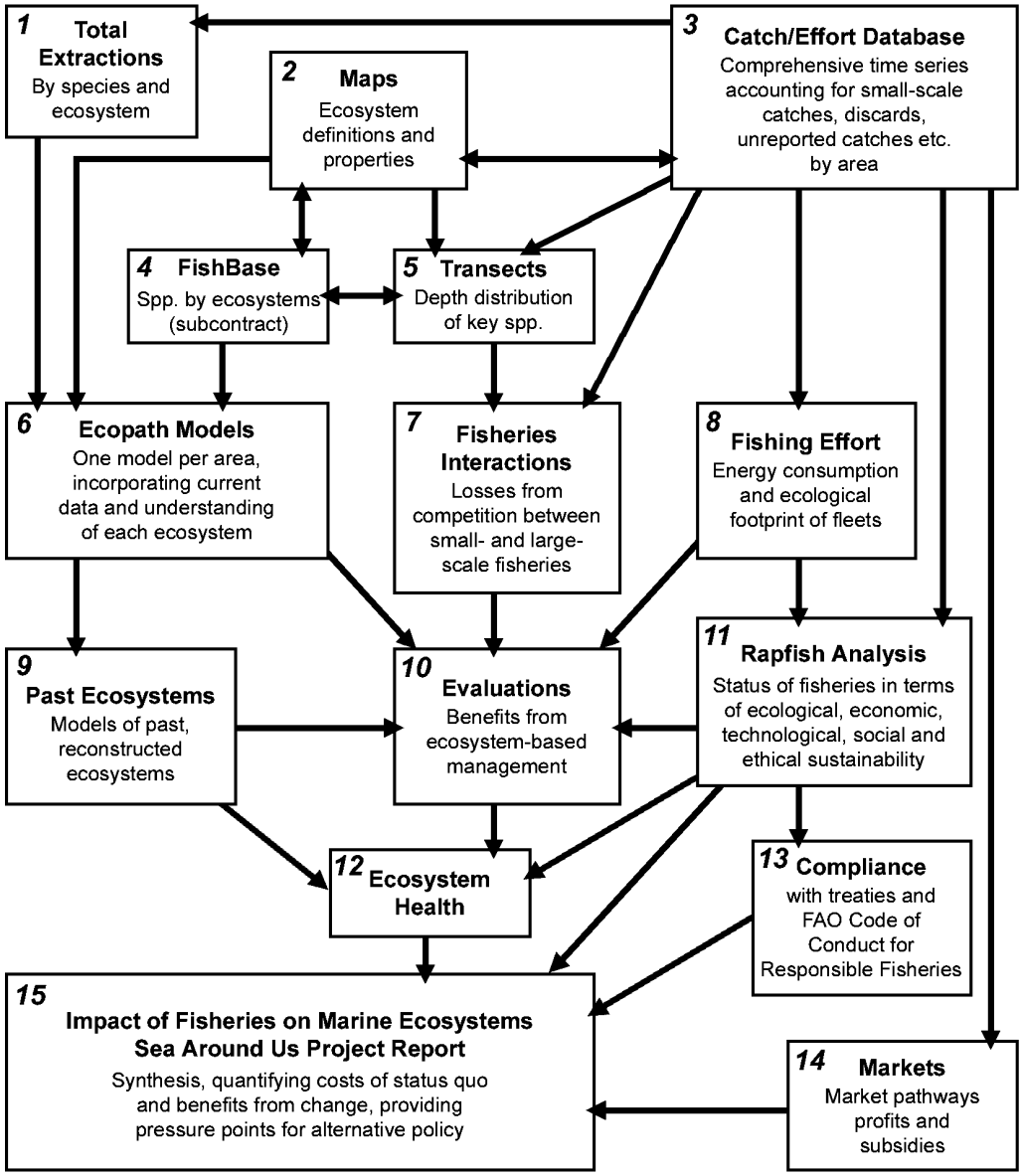

Figure 2. Conceptual diagram (originally published in 2000) illustrating the relationships of 15 methodological elements of the *Sea Around Us* Project (see text).

sensitive habitats (e.g., seamounts [22]) or with marine mammals (23) and seabirds (24). This may be illustrated for marine mammals, which have been alleged to consume so much fish and invertebrates that massive culls may be necessary to re-establish ecosystem balance (25, 26).

Although we were able to confirm that, jointly, 115 species of marine mammals consume about three to four times the world catch of 150 million tonnes (i.e., roughly accounting for illegal, unreported, and unregulated, or IUU, catches [27]), it was evident that the bulk of this consumption involved taxa not consumed by humans (giant squids, mesopelagic fishes, etc.) but consumed in areas (the central gyres of the oceans, and other low productivity ecosystems) where tunas, not consumed by marine mammals, are the only commercial species. Thus, and this came to us as a surprise, the dietary overlap between marine mammals and fisheries is minuscule when examined on a global basis, and culling all whales and other marine mammals in the world would not reverse the downward trend of most fisheries (23). This implies that a coexistence of most fisheries and marine mammals is possible.

We found here that the global scale used by the *Sea Around Us* Project allowed reframing of an issue that had so far been only based on a myopic perspective.

FISHERIES AND MARINE BIODIVERSITY

Fisheries strongly affect marine biodiversity (28), and for most countries of the world, maintaining the biodiversity within their EEZ in the face of fisheries impacts is a daunting task. In fact, most countries do not have the resources to even list the species that occur in their EEZ, although as parties of the Convention of Biological Diversity they are mandated to do so.

Therefore, through "deep linking" with FishBase (http://www.fishbase.org) (Fig. 2, item 4), which assigns to countries the 30 000 species of fish now extant, the *Sea Around Us* Project makes available, for each of the world maritime countries, a complete list of the marine fish found in their EEZ, along with information on their biology and status (29).

Similar authoritative lists cannot at present be offered for other marine groups. Although there is a multitude of national and regional taxonomic databases available online, very few are global in scope. Moreover, most of the databases fail to emulate FishBase in providing biological data (body size, feeding habits, habitats, etc.), such that the organisms in question can be studied as elements of ecosystems, rather than as desiccated specimens in museums.

To help overcome this situation, the *Sea Around Us* Project, here with support from the Oak Foundation, has launched

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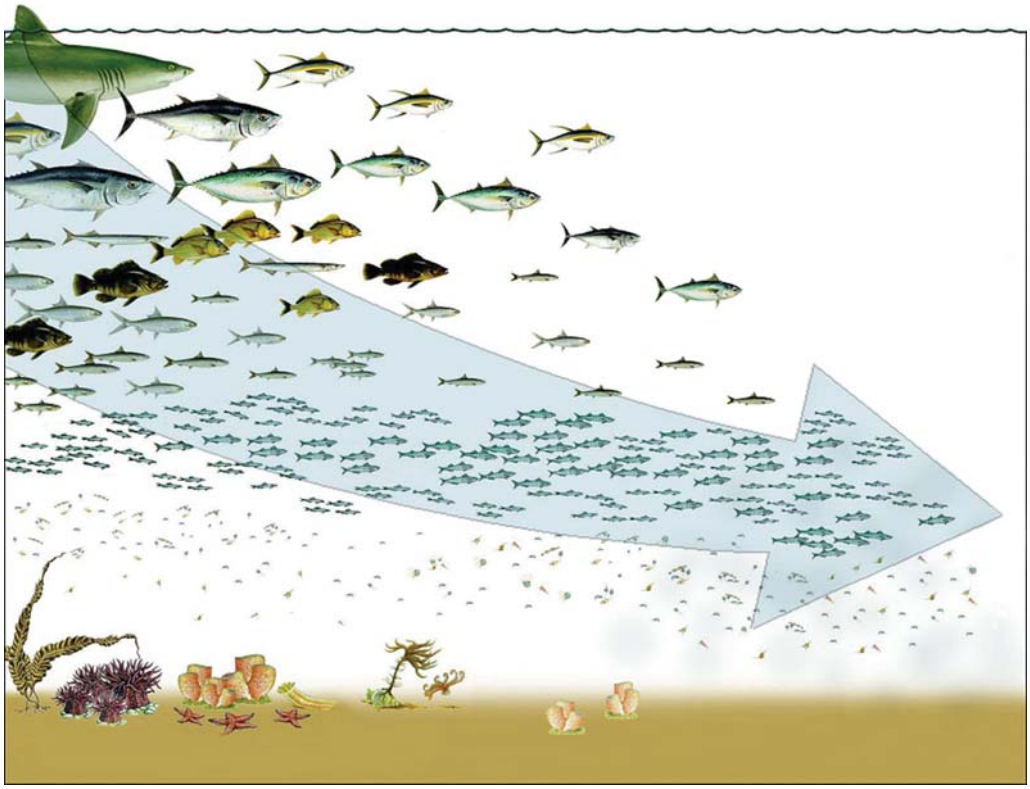

Figure 3. Fishing down marine food webs means that the fisheries (blue arrow), having at first depleted the more vulnerable large fish at the top of various food chains, must target small fish and end up targeting very small fish and invertebrates, including jellyfish. In some parts of the world, the fisheries have indeed gone all the way down, and jellyfish fisheries are on the rise. The bottom invertebrates at the lower left part of the graphs disappear because of trawling, which leaves large mudbeds in its wake. This graph summarizes much of the *Sea Around Us* work and is part of most of our presentations. (Design: Daniel Pauly; Artist: Aque Atanacio, Los Baños, Philippines.)

SeaLifeBase (http://www.sealifebase.org), a database and portal intended to eventually cover, in FishBase-like fashion, the about 200 000 species of animals and plants so far reported from marine waters. As of early 2007, SeaLifeBase and the associated Sea Life Portal, which access information in allied databases, presently gives access to nearly 50 000 species, including all marine vertebrates (marine mammals, seabirds, marine reptiles, and fishes) and all commercial species of invertebrates.

Another aspect of biodiversity that the *Sea Around Us* Project engages in is the reconstruction of historic maritime expeditions, which can be used, along with historical narratives, to infer long-term changes in the biodiversity of major groups, such as seabirds, marine mammals, and sea turtles (30, 31).

FISHERIES AND MARINE ECOSYSTEMS

Fisheries affect marine ecosystems directly, through the removal of biomass, that is, the very fish and invertebrates that define and shape the food webs of these ecosystems, and indirectly, through the destruction of habitat, notably by bottom trawling (33).

The *Sea Around Us* Project facilitates the study of the impacts and their mitigation by facilitating the worldwide transition to ecosystem-based fisheries management (32). Here the contribution of the project is mainly through the development and dissemination of the Ecopath with Ecosim (EwE) modeling approach and software, now applied worldwide to describe fisheries ecosystems and to simulate various management scenarios (34) (Fig. 2, items 6 and 10).

Some of the models constructed as part of this process are also used for analyses by the *Sea Around Us* Project. Notably, EwE models, representing different periods and areas and constructed mainly by scientists collaborating with the project, were used to contrast fish biomass before the onset of industrial fishing with present biomass in the North Atlantic (35), West Africa (36) and Southeast Asia (37) (Fig. 2, items 6, 9, and 12).

Also, in collaboration with other groups, the *Sea Around Us* Project identified indicators of the ecosystem impact of fisheries, derived from the catch database, and made the information available to all the world's maritime countries.

In 2004, the Conference of the Parties to the Convention on Biological Diversity (CBD) identified a number of indicators to monitor progress toward reaching the target to "achieve by 2010 a significant reduction in the current rate of biodiversity loss" (38). The Marine Trophic Index (MTI), which measures the extent to which we are "fishing down marine food webs"(42), is one of the eight indicators that the Conference of the Parties to the CBD identified for immediate testing of their ability to measure progress towards the 2010 target. The MTI is defined as the mean trophic level of fisheries catches and typically shows a descending trend for most countries due to the declining biomass and hence catches of large, high-trophic–level fish (Fig. 3) (39, 40, 41).

To facilitate the implementation of this indicator, we provide on the *Sea Around Us* Project website time series of the MTI and related indicators for each country from 1950 to the present based on official catch statistics. This confirms that fishing down marine food webs is ubiquitous but also shows, however, that the detailed catch data required for such a simple indicator as the MTI are lacking for many countries, a theme to which I return below.

We also collaborated with Redefining Progress (see http://www.rprogress.org) in extending footprint analysis (42) to cover fish and other aquatic resources, which involved drawing on the concepts and methods developed earlier (43). This led to the output, for all EEZs of the world, of the time series of the primary production required to sustain the fisheries (national and distant-water fleets) operating in those EEZs, as a fraction of the primary production therein (Fig. 2, item 8). Also, we generated time series for all maritime countries of the world of the primary production required by their fisheries, wherever conducted, again expressed as a fraction of the primary production in their EEZ. These outputs, available on our website, were recently used by Redefining Progress for an analysis of the "Fishprint of Nations" (44). We intend to complement these outputs by adding the primary production

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required for imported fish, which will allow the identification of the countries most dependent on the fish of others.

The *Sea Around Us* Project, in collaboration with the World Conservation Monitoring Center, the World Wide Fund for Nature, and other groups, has created a global database of Marine Protected Areas (MPAs), from which the tiny (0.6%) part of the ocean that is currently protected could be reliably estimated, along with the growth of this coverage, about 4 to 5% each year. This implies that none of the targets will be attained that have been set for global networks of MPAs (e.g., 10% of the world's oceans by 2010, as required by the CBD) (45).

These various products, pertinent to the health of ecosystems (Fig. 2, item 12) and to their ability to deliver services, enabled us to contribute significantly to the work of the Millennium Ecosystem Assessment, notably to the two marine chapters on "coastal" and "fisheries" (offshore) ecosystems of its *Current State and Trends* volume (46, 47).

THE GOVERNANCE OF FISHERIES

The governance of fisheries in most countries involves a lead agency, often a Ministry of Fisheries or a department within the Ministry of Agriculture, that operates within a fisheries development plan or act. Also indirectly invested in fisheries is a Ministry of the Environment or its equivalent, surrounded by many environmental nongovernmental organizations (NGOs).

On the governance page of our website, we document and list these institutions (and their URLs) for every country of the world (to the extent possible), along with profiles of the fisheries for most of the important fishing nations, the fisheries-related treaties, conventions to which they are parties, and the fisheries access agreements into which they have entered.

This provides a frame for a very important table that presents the subsidies that countries award their fisheries by type and likely effect on the fishery (48) (Fig. 2, item 14). Our global estimate of fisheries subsidies is of USD 30 to 34 billion in 2000, twice the value assumed so far by the World Bank (49) and used in negotiations at the World Trade Organization.

REACHING BEYOND SCIENTIFIC AUDIENCES

One of the reasons the destruction of marine life by heavily subsidized fishing fleets could proceed as far as it did is because the public at large has long remained misinformed about the nature of modern industrial fisheries. Essentially, the public, until recently, had a romantic image of fishers and fisheries. On the other hand, the environmental NGOs that could have corrected this benign view of fisheries largely depended for their analyses on fisheries data from government laboratories, mainly assembled and pertinent to the tactical (year-to-year) management of industrial fleets and generally useless for demonstrating the ecosystem impact of fisheries. In a way, the NGOs have depended for years on what may be viewed as crumbs falling from the table of regulatory agencies.

The *Sea Around Us* Project was designed to counter this, its purpose being the development of what may be called "fisheries conservation science," geared toward maintaining ecosystem configurations likely to allow for sustainable fisheries (Fig. 2, item 15) and not to the largely unsustainable fisheries that we have now. This is also the goal, incidentally, of most NGOs working on the nexus of fisheries and ecosystems, even if the fishing industry doesn't see it.

To achieve its purpose, the *Sea Around Us* Project must therefore pursue a dual strategy of contributing to the technical peer-reviewed literature to maintain the scientific credibility of its members and reaching out to the members of the environmental NGO community (and the philanthropic foundations that provide most of its funding) and to the public at large using a range of products (magazine and newspapers articles, policy briefings, public lectures, etc.) suited for various audiences. One major product (and tool) is our website (http://www.seaaroundus.org), which provides maps that can communicate complex information even to lay audiences.

Our website presents for each country of the world (and also for the 64 large marine ecosystems so far defined (50) but not discussed here) what we believe is key information on the marine fisheries and ecosystems of the world (Fig. 2, items 1, 2, and 3). The information on fisheries and ecosystems we provide could be far more detailed for some developed countries. However, this would leave most developing countries behind, which would seem inappropriate, given that it is fish caught along the coasts of, or exported from, developing countries that now largely supply markets in developed countries (51).

Thus, the *Sea Around Us* Project, now mature, will continue to exploit its global niche, that is, concentrate on global fisheries issues, and only add worldwide datasets to its website.

OUTLOOK

We have plans for the future. In the short term, we would like to improve the quality and quantity of our coverage of the fisheries and ecosystems of maritime countries. This especially applies to the fishing effort of global fisheries, which we will use for inference on biomass trends of commercial species worldwide (Fig. 2, item 3) and for inferences on the profitability of fisheries (Fig. 2, item 14). This also applies to small-scale fisheries, which historically have been marginalized (52) and whose important role in rural economies needs to be stressed, both at national and global levels (53). Notably, this must involve the re-estimation of their catches, which tend to be much higher than reported in official catch statistics (54), and comparative evaluation of their contributions to rural incomes and other social benefits relative to the industrial fisheries that encroach on their coastal fishing grounds (Fig. 2, item 7).

This also applies, more generally, to IUU catches, which are much higher than so far assumed, as we shall show in forthcoming reports. They represent but one aspect of noncompliance with national and international agreements (Fig. 2, item 13), another topic we will emphasize in the near term, notably by ranking countries by various attributes of their fisheries and the state of their EEZ (Fig. 2, item 11).

In the medium term, we will endeavor to motivate a number of environmental NGOs and other institutions to form a consortium for maintaining and further developing the *Sea Around Us* databases and website, similar to the eight institutions that constitute the FishBase consortium, ensuring the permanence of this enormously successful database. The hope here is that the various *Sea Around Us* products become bridges, facilitating communication about what is, after all, a complex topic and thus contribute to addressing the sixth and most important question in the Introduction.

As for the long term, either we resolve our overfishing and mitigate its effects on biodiversity as part of taking environmental issues seriously or we continue to allow the economy to decide how we interact with our planet. In the latter case, global warming and its attendant ills will do us in, and there will be no need for fisheries management (56).

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